PUBLICLY AVAILABLE SPECIFICATION

# IEC PAS 62458

Pre-Standard

First edition
2006-01

# Sound system equipment – Electroacoustical transducers – Measurement of large signal parameters

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# SOUND SYSTEM EQUIPMENT –
# Electroacoustical transducers –
# Measurement of large signal parameters

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# INTRODUCTION

The behaviour of loudspeakers is traditionally described by parameters according to IEC 60268-5, assuming a linear behaviour. By adding parameters, derived from a non-linear model, a more precise description can be made for design purposes and quality control in order to get a more reproducible behaviour for the manufacturing of equipment.

The dominant non-linearities in electro-dynamical transducers are directly related to the displacement $x$ of the voice coil. The force factor, $Bl(x)$ , of the motor, the voice coil inductance, $L_e(x)$, and the stiffness, $K(x)$, of the mechanical suspension are not constant but vary significantly with the instantaneous displacement, $x$. This generates distortion and limits the maximal output of the transducer. The measurement of harmonic and intermodulation distortion according to IEC 60268-5 with special test stimulus only gives characteristic symptoms of the non-linearities. The measurement of the non-linear parameters reveals the physical cause of the dominant distortion directly. This information is not only important for loudspeaker diagnostics but also for the synthesis of loudspeaker systems and the development of electrical control systems dedicated to loudspeakers.

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# SOUND SYSTEM EQUIPMENT –
# Electroacoustical transducer –
# Measurement of large signal parameters

## 1 Scope

This PAS applies to transducers such as loudspeakers, headphones, shakers, and other actuators using either an electro-dynamical or electro-magnetic motor coupled with a mechanical suspension. The measurement results are needed for engineering design purposes and for quality control.

The measurement method provides the parameters of a non-linear large signal model (as shown in Figure A.1) which describes the effect of the dominant non-linearities inherent in those transducers. The basic terms and measurement conditions are defined for static and dynamic methods.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60268-5, *Sound system equipment - Part 5: Loudspeakers*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

**3.1**
**force factor, $Bl(x)$**
coupling factor between the electrical and the mechanical side of the electro-dynamical transducer describing the relationship between driving force

$$F = Bl(x) \times i \tag{1}$$

and electrical input current $i$ and back EMF

$$u_{\mathrm{EMF}} = Bl(x) \times v \tag{2}$$

and velocity $v$ of the coil

**3.2**
**electrical coil impedance, $Z_e$**
ratio of the complex amplitudes of electrical voltage and current at the terminals for a small sinusoidal excitation if the voice coil is mechanically clamped and no back EMF is generated ($u_{\mathrm{EMF}}$ = 0). The electrical impedance also depends on the position $x$ of the voice coil. The electrical coil impedance, $Z_e$, may be approximated by a lumped parameter model (Figure 1) using the d.c. resistance, $R_e$, the inductance, $L_e(x)$, and additional shunted inductances, ($R_2(x)$, $L_2(x)$), to model the electrical input impedance of the transducer at higher frequencies

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**3.3**
**stiffness, *K(x)*, of the suspension**
stiffness describing the restoring force

$$F_R = K(x)x \tag{3}$$

of the suspension generated by a displacement $x$

**3.4**
**compliance, *C*(*x*), of the suspension**
reciprocal quantity, $C(x) = 1/K(x)$, of the mechanical stiffness, $K(x)$

**3.5**
**maximal peak displacement, $x_{MAXd}$**
deplacement which considers the distortion in the loudspeaker's output signal. $x_{MAXd}$ is defined as the voice-coil peak displacement at which the maximum value of either the total harmonic distortion, $d_t$, or the second-order modulation distortion, $d_2$, or the third-order modulation distortion, $d_3$, in the radiated sound pressure is equal to a defined threshold, $d$ (used as subscript in $x_{MAXd}$).

The driver is excited by the linear superposition of a first tone at the resonance frequency, $f_1 = f_s$, and a second tone, $f_2 = 8{,}5\,f_s$, with an amplitude ratio of 4:1. The total harmonic distortion, $d_t$, assesses the harmonics of $f_1$ and the modulation distortions, $d_2$ and $d_3$, are measured according to IEC 60268-5. It is recommended that the driver be operated in a baffle (half-space) to measure the sound pressure in the near field and to use the threshold $d$ = 10% and to state $x_{MAX10}$.

**3.5**
**force factor limited displacement, $x_{Bl}$**
factor implicitly defined by the minimal force factor ratio

$$Bl_{\min}(x_{Bl}) = \min_{-X_{Bl}<x<X_{Bl}} \left( \frac{Bl(x)}{Bl(0)} \right) \times 100\% \tag{4}$$

which is the ratio of the minimal value of the force factor, *Bl(x),* in the working range, $\pm x_{Bl}$,,referred to the *Bl* value at the rest position $x = 0$. After defining the threshold, $Bl_{min}$, the peak displacement, $x_{Bl}$, can be found in the non-linear *Bl(x)*-characteristic

**3.6**
**inductance limited displacement, $x_L$**
displacement implicitly defined by maximal variation of the electrical input impedance

$$Z_{\max}(x_L) = \max_{-X_L<x<X_L} \frac{|Z_e(x,f_2) - Z_e(0,f_2)|}{|Z_e(0,f_2)|} \times 100\ \% \tag{5}$$

at frequency $f_2 = 8{,}5\ f_s$ (using the resonance frequency, $f_s$) within the working range $-x_L < x < x_L$ referred to the impedance at the rest position $x = 0$

**3.7**
**compliance limited displacement $x_C$**
displacement implicitly defined by minimal compliance ratio

$$C_{\min}(x_C) = \min_{-X_C<x<X_C} \left( \frac{C(x)}{C(0)} \right) \times 100\% \tag{6}$$

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which is the ratio of the minimal value of the force factor, $C(x)$, in the working range $\pm x_C$ referred to the $C$ value at the rest position $x = 0$. After defining the threshold $C_{\text{min}}$ the displacement limit, $x_C$, can be found in the non-linear $C(x)$ characteristic

**3.8**
**excursion limit, $x_{\text{limit}}$**
limit describing the maximal travel of the coil without considering the distortion in the output signal. This value may be derived from the geometry of the moving coil assembly and the suspension but should be verified by practical testing to ensure that the loudspeaker can be operated up to $x_{\text{limit}}$ without being damaged

**3.9**
**static method**
measurement technique which determines the non-linear parameters of the transducer by using a d.c. signal of certain magnitude $U_i$ (for example, voltage) as stimulus. To measure the non-linear parameters within the working range $-x_{\text{peak}} < x_i < x_{\text{peak}}$ with sufficient resolution, multiple measurements are performed where the magnitude of the d.c. stimulus is changed (for example, voltage $U_i = i \times U_{\text{step}}$ with $I = 1, \dots N$). At each working point, $i$, the displacement, $x_i$, and other relevant state variables (force $F_i$, current $i_i$) are measured after the transducer has reached steady state. Due to the visco-elastic behaviour of the suspension material, the settling time may exceed multiple seconds. The values $K(x_i)$, $Bl(x_i)$ *and* $L_e(x_i)$ at the working point, $x_i$, are estimated by using equations (1), (3) and (4)

**3.10**
**point-by-point dynamic method**
measurement technique which determines the non-linear parameters of the transducer by using a d.c. signal, $U_i$ (for example, voltage), superimposed with a small a.c. signal, $U_{\text{ac}}$, as stimulus. To measure the non-linear parameters within the working range $-x_{\text{peak}} < x_i < x_{\text{peak}}$ with sufficient resolution, multiple measurements are performed where the magnitude of the d.c. stimulus is changed (for example, voltage $U_i = i \times U_{\text{step}}$ with $i = 1, \dots$ N). At each working point, $i$, the d.c. displacement, $x_i$, and other relevant d.c. and a.c. state variables (a.c. part of the displacement, $x_{\text{ac}}$, force, $F_{ac}$, current, $i_{ac}$) are measured after the transducer has reached steady state. Due to the visco-elastic behaviour of the suspension material, the settling time may be multiple seconds. The amplitude of the a.c. stimulus is sufficiently small to ensure that the transducer behaves linearly ($K(x_i+x_{\text{ac}}) \approx$ const., $Bl(x_i+x_{\text{ac}}) \approx$ const. and $L_e(x_i+x_{\text{ac}}) \approx$ const.). The parameters of a linear loudspeaker model are estimated at the particular working point, $x_i$, by using the measured a.c. state variables only. Whereas some small signal parameters (force factor $Bl(x_i)$ and inductance $L_e(x_i)$ are identical to the large signal parameters measured by other methods, this technique provides the incremental stiffness, $K_{\text{inc}}(x_i)$, which has to be transformed into the regular stiffness by integration

$$K\left(x\right) = \frac{1}{x}\int_{0}^{x} K_{inc}(x)dx \tag{7}$$

**3.11**
**full dynamic method**
method determining the non-linear parameters of the transducer by using an audio-like a.c. stimulus of sufficient amplitude to operate the transducer in the full working range. Relevant state variables (voltage, current, displacement) are measured and are the basis for the identification of non-linear parameters giving an optimal fitting of the non-linear model (for example, lumped model in Figure 1) to the particular transducer. Usually, no d.c. signal is used as stimulus

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## 4 Test equipment

The essential elements of the test equipment needed are as follows:

– means for generating a stimulus supplied to the transducer;
– sensors for measuring relevant state variables (voltage, current, force or displacement) at the transducer;
– means for estimating optimal parameters of the lumped parameter model which explains the relationship between the measured state variables.

## 5 Test method

a) The transducer is operated under working conditions, which corresponds to the final application.

b) The loudspeaker is excited by a stimulus which operates the transducer in the permissible working range.

c) Relevant state variables are measured at the transducer.

d) The optimal parameters of the model are estimated by minimizing the error between modeled and estimated output.

## 6 Test result

Measurement conditions, such as mounting of the transducer (horizontal or vertical position, enclosure, free air, etc.), shall be reported.

The non-linear parameters (for example, force factor, $Bl(x)$) shall preferably be reported as a graphical representation showing the parameter as a function of state variable (for example, displacement, $x$, as shown in Figures 1 to 3). Positive displacement, $x$, corresponds to a deflection of the coil away from the back-plate. It is recommended that the displacement axis be labeled with verbal comments to support the orientation of the coil-in and coil-out position.

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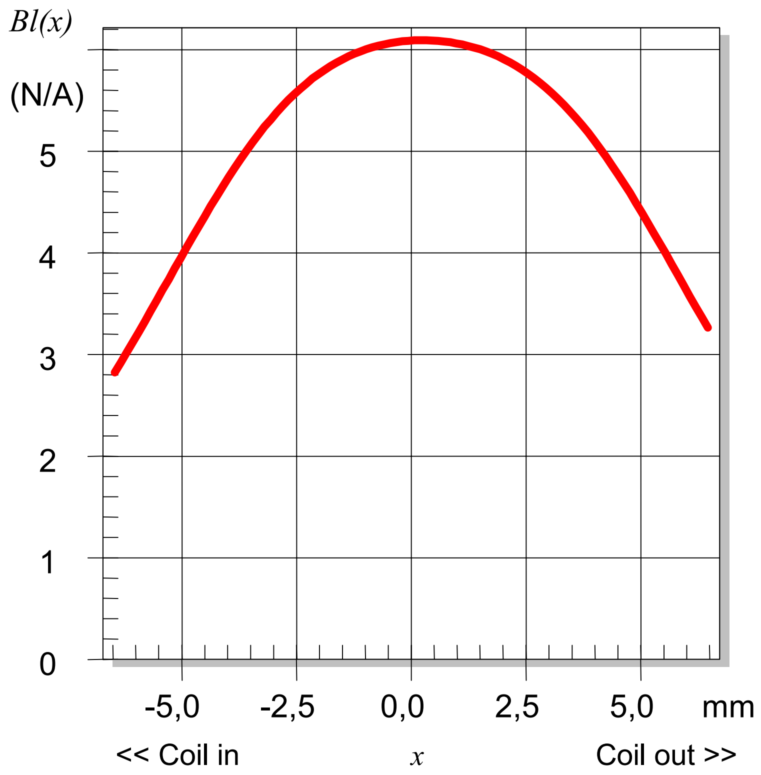


**Figure 1 – Force factor, *Bl*(*x*), versus displacement, *x***

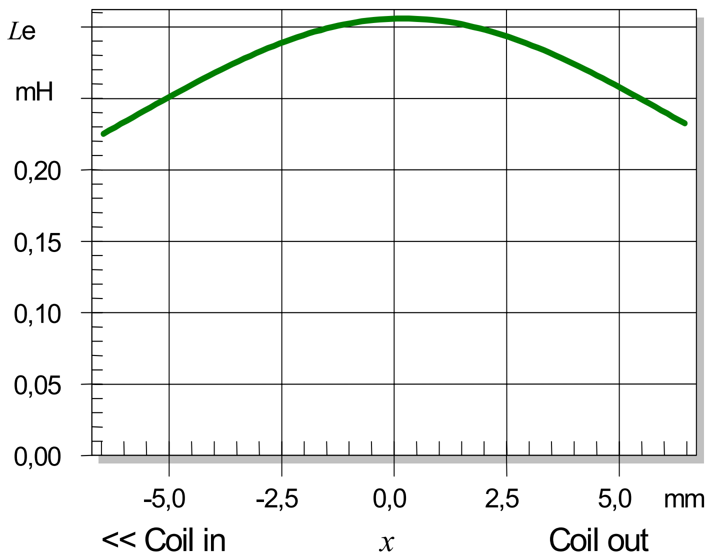


**Figure 2 – Inductance, $L_e(x)$, versus displacement, *x***

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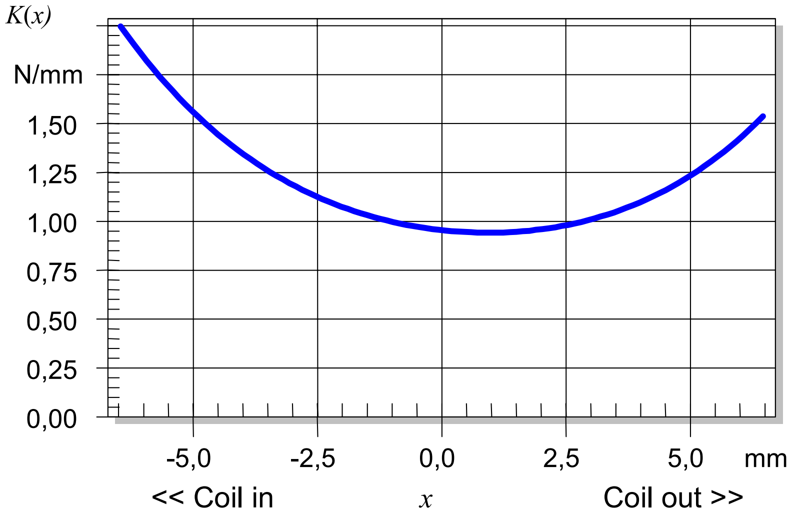


**Figure 3 – Stiffness, $K(x)$, versus displacement, $x$**

Alternatively, the displacement varying parameters $Bl(x)$, $L_e(x)$ and $K(x)$ may be reported by the coefficients $b_i$, $l_i$ and $k_i$, of the power series expansion

$$Bl(x) = \sum_{i=0}^{N} b_i x^i \tag{8}$$

$$L_e(x) = \sum_{i=0}^{N} l_i x^i \tag{9}$$

$$K(x) = \sum_{i=0}^{N} k_i x^i \tag{10}$$

respectively, with $i = 0, 1, \dots N$. The peak displacement, $x_{peak}$, occurring during the measurement, which describes the limits of the valid fitting range, is also presented.

The peak displacement, $x_{MAXd}$, shall be reported with the specified distortion threshold, $d$, used. For example, for the threshold $d$ =10 %, the peak displacement is stated as

$x_{MAX10}$ = 2 mm

The peak displacements $x_{Bl}$, $x_C$ and $x_L$ limited by force factor, compliance and inductance, respectively, shall be reported with the minimal force factor ratio, $Bl_{min}$, the minimal compliance ration, $C_{min}$, and the maximal impedance ratio, $Z_{max}$, used as threshold. For example,

$x_{Bl}$ = 3 mm ($Bl_{min}$ = 82 %)

$x_C$ = 2 mm ($C_{min}$ = 75 %)

$x_L$ = 4 mm ($Z_{min}$ = 10%)

To keep the peak displacement, $x_{MAX10}$, comparable with the peak displacements $x_{Bl}$, $x_C$ and $x_L$ related to the dominant non-linearities, it is recommend that $C_{min}$ = 75 %, which generates about $d_t$ = 10 % total harmonic distortion, and $Bl_{min}$= 82 % and $Z_{max}$= 10 % causing about 10 % modulation distortion, be used.

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# Annex A
(informative)

# Additional information

## A.1 Lumped parameter model

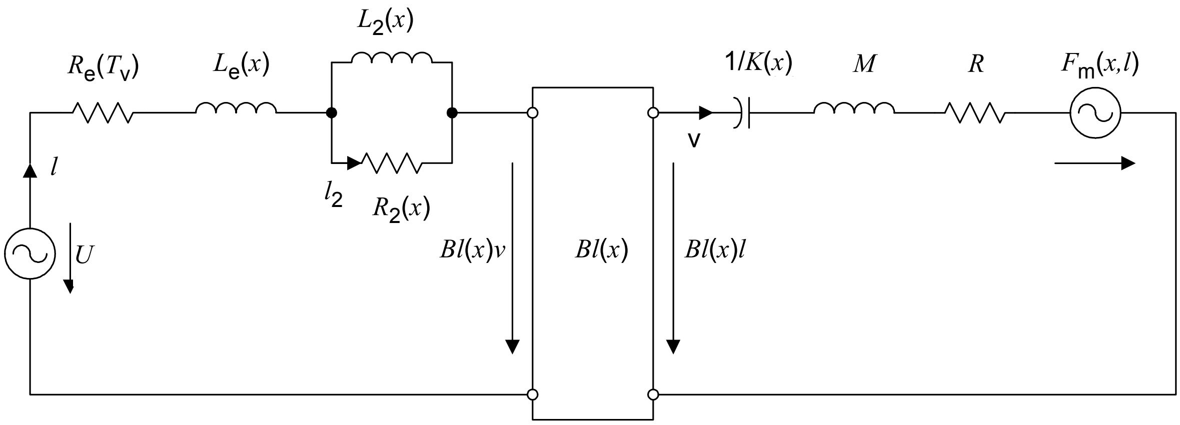


**Figure A.1 – Lumped parameter model of an electro-dynamical transducer**

Figure A.1 shows the electrical equivalent model of an electro-dynamical transducer using lumped elements $R_e$, $L_e(x)$, $L_2(x)$ and $R_2(x)$ to represent the electrical coil impedance $Z_e(x,f)$. The force factor $Bl(x)$ is represented as a transformer coupling the electrical with the mechanical side. The mechanical and acoustical systems are lumped to a resonator comprising a moving mass, $m$, a stiffness, $K(x)$, and a resistance $R$. The displacement varying inductances $L_e(x)$ and $L_2(x)$ cause a reluctance force $F_m(x,l)$ which may be interpreted as an additional electro-magnetic driving force.

## A.2 Memory effects of the suspension

The properties of the suspension material depend not only on the ambient conditions but also vary significantly with time. There are non-reversible processes related with the breaking-in and the ageing of the suspension. There are reversible processes which are related to the visco-elastic behaviour of the suspension material. For example, a displacement of a spider causes a temporary deformation of the fibre geometry which is the cause for the creep effect [3] [1] and loss of stiffness $K(0)$ at the rest position $x = 0$ after performing a large peak displacement $x_{peak}$ [4]. The memory of the suspension causes significant differences between the results of static, point-by-point dynamic and full dynamic methods. Since only the dynamic method uses an audio-like excitation signal, this method is able to describe the behaviour of loudspeakers under normal working conditions.

## A.3 Interpretation of the large signal parameters

The variation of the non-linear parameters (for example, force factor $Bl(x)$) versus state variables (for example, displacement $x$) reveals the relationship between the constructional and geometrical properties of the transducer and the non-linear distortion generated in the output signal. Asymmetrical variations, caused by an offset of the coil, for example, mainly

———————

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contributes to second-order distortion while symmetrical variation (caused by a low voice-coil overhang) contributes to third- and other odd-order distortion.

Displacement varying force factor and inductance can produce significant intermodulation distortion between a low-frequency tone and any other tone in the audio band. The non-linear stiffness produces distortion components close to the resonance frequency.

While the parameters $Bl(x)$, $K(x)$ and $L_e(x)$ represented as graph or power series expansion gives full information on the transducer non-linearities within the measured working range, the peak displacements $x_{Bl}$, $x_C$ and $x_L$ and $x_{limit}$ are a result of a significant data reduction [2].

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[1] Clark D., *Precision Measurement of Loudspeaker Parameters*, J. Audio Eng. Society, vol. 45, p. 129-140, March 1997.

[2] Klippel W., *Assessment of Voice-Coil Peak Displacement* $x_{\mathrm{MAX}}$, J. Audio Eng. Society vol. 51, Heft 5, p. 307-323, May 2003.

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